Success Story

Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Microwave-Assisted Plasma (MAP) Manufacturing of Carbon Fibers

Background

Significant weight reduction and corresponding increases in fuel economy can be achieved in automobiles by replacing dense metals with strong, lightweight materials. Carbon fiber reinforced composites are an excellent candidate for this light-weight material and offer significant weight-saving potential because of their remarkably high strength, high elastic modulus, and low density. Composites are structures containing two or more components, in this case the reinforcing fiber and a resin.

Other valued properties of carbon fiber composites are good fatigue resistance, dimensional stability, corrosion resistance, lower tooling costs, and greater design flexibility. By designing composites into an entire vehicle subsystem, the total number of parts to be formed and later joined can be reduced. Such a systems approach leads to significant reductions in vehicle weight and simplified manufacturing.

For example, replacement of steel and aluminum body panels and chassis components with structurally equivalent carbon fiber composites offers up to 68% weight reduction, resulting in savings of up to 40% in fuel consumption. Carbon fibers have been used in high-performance applications for several decades but their relatively high cost has constrained their use in the automotive industry. Carbon fibers with the properties needed for automotive applications currently sell for $6 to $16 per pound. A cost of $3 per pound is believed to be the threshold for widespread automotive use.

Carbon fibers produced by ORNL's Microwave-Assisted Plasma (MAP) process have significantly higher tensile modulus and strength than fibers produced by conventional means.

Carbon fibers are derived from one of two precursor materials, either pitch or poly-acrylonitrile (PAN) fibers. Pitch-based carbon fibers have much greater stiffness and are used in high-performance applications, such as military aircraft, spacecraft, and missiles. They are less suitable for automotive applications because of their cost and relative brittleness. PAN-based carbon fibers are lower in cost and are used primarily in sporting goods and construction. They are under intense development to further reduce costs, and tailor their properties for myriad applications.

Magnesia-stabilized zirconia had an adequate CTE (9 ppm/˚C) and showed no loss of strength from environmental or temperature factors.

Cummins conducted extensive bench and rig testing of the new timing plunger, and additional engine testing proved its ability to withstand scuffing and seizing even with water introduced into the fuel.

A significant barrier to timing plunger implementation was the lack of high-volume centerless grinding capability to grind the outer diameter of the plungers to sub-micron tolerance levels. Cummins has since developed this capability and performs the final outer diameter grinding operations in-house.

Commercialization

A zirconia timing plunger was introduced in 1995 under the CELECT™ trademark. Following the success of the timing plunger, a CELECT™ zirconia metering plunger was introduced in 1997. This component displayed an increased level of complexity requiring sharp metering edges in two locations. The grinding and handling operations were improved to maintain these edges.

In 1998, Cummins introduced the CAPS™ common rail fuel system for mid-range engines. The new fuel system contained a zirconia pumping plunger, and was the first system at Cummins to be introduced into production with a ceramic component included in the design and development process.

Cummins is constantly seeking to improve the performance of its new ceramic injectors. In 2001 a new, higher strength zirconia showing improved robustness and closer matching under operating conditions was introduced for all three applications.

Benefits

- Zirconia injectors resist scuffing and wear caused by the reduced lubricity of low-sulfur fuel
- Close cooperation among ORNL, Cummins, and ceramic suppliers has resulted in the development of improved zirconia ceramics
- The successful incorporation of zirconia injectors will allow the further advancement of emission reduction technologies for diesel engines

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